Engineering Experiments Utilizing an Automated Breadmaker
By

Robert P. Hesketh, C. Stewart Slater, and Carol Rea Flynn,
Chemical Engineering, Rowan University, Glassboro NJ 08028-1701
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Breadmaking is a technology with a long history, starting with the Egyptians baking loaves of bread over 6000 years ago. Since then, the process of bread making has become fully automated through the use of bulk transportation of ingredients, large mechanical mixers, conveyors, environmentally controlled proofing chambers, high efficiency ovens, cutters, and packaging equipment. This process of bread making can be classified into several unit operations including particle transport, mixing, fermentation, and baking. This industrial process has been fully automated in the relatively new bench top breadmaking machines. At Rowan we have used breadmaking machines for a number of experiments starting with freshman level mass balances, reverse engineering, data acquisition, to upper level heat transfer, biochemical reactions, and mixing. These relatively modest priced machines also have the added advantage of filling the laboratory with the ever pleasing aroma baking bread!

This paper contains descriptions of the experiments that have been conducted with breadmakers and presents methods for incorporation of these ideas into existing engineering courses.

Purpose:

The breadmaker uses many chemical engineering principles. Data acquisition, which is useful to anybody in engineering, and can be taught at a freshmen level, heat transfer, which can be done at a junior level, and many others that we will not discuss here. In this workshop we will show you experiments starting from a freshman level data acquisition, to juniors level heat and mass transfer.

Background:

Introduction

The Egyptians made the first loaves of bread over 6000 years ago. Since then, the process of bread making has become fully automated through the use of bulk transportation of ingredients, large mechanical mixers, conveyors, environmentally controlled proofing chambers, high efficiency ovens, cutters, and packaging equipment. The process of bread making can be separated into a series of unit operations – transportation of materials, mixing, fermentation, and baking. Each unit operation has mechanical / electrical function and/or chemical reactions associated with the unit operation.

Raw Materials & Addition of Ingredients

Bulk handling of ingredients is commonplace. Raw materials are packaged in large bags, tanks, vats, etc. and brought to the bakery via truck, refrigerated tank system, or rail car. Commercial bakeries are equipped to store ingredients in humidity and temperature controlled silos, tanks, and warehouses.

The ingredients are added to the "mix" or batch in several different ways. Dry ingredients are generally weighed and dumped into the batch via large rolling troughs. Liquid ingredients are typically metered and flow into the batch via a piping system.

Mixing

Mixing is the second step in the baking process. The manner, which it is carried out, determines the state of dispersion of ingredients and, in turn, the efficiency of processing and quality of the final product.

Most bread processes incorporate the premixing of the dry ingredients. This ensures uniformly distributed ingredients, especially small quantity ingredients such as salt, sugar, or vitamins. Premixing prevents localized concentrations of minor ingredients and reduces the total mixing time, hence, reducing the heating that normally accompanies the thorough and lengthy mixing of dough.

Incorporation of water – Liquid Phase

When water is added to dry flour, it is adsorbed, initially, to form a one-phase system with the flour; this water is "said to be bound". The dry gluten, a constituent of flour, swells in water. When the water content reaches a value in the region of 30-35% by weight, a second aqueous phase appears. This is a liquid phase, which dissolves soluble flour components, which becomes dispersed in dough during mixing. The liquid phase provides the medium for reactions to take place in the dough and for carbon dioxide to dissolve and diffuse to the gas cells. The importance of the liquid phase for gas production in fermenting dough is to provide the aqueous solution of sugar to "feed" the yeast.

Proper amount of water provides an aqueous phase, which is dispersed not continuous. The aqueous phase remains dispersed in dough if the water content remains below approximately 35% by weight. With increase water content above 35%, the electrical conductivity shows a dramatic increase, indicating a continuous phase rather than a dispersed liquid phase.
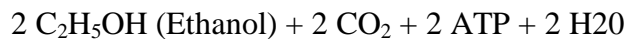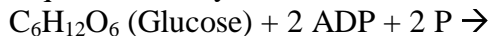
Bulk Fermentation or "Rest" Period – Biotechnology of Yeast

Bulk fermentation incorporates the 6000-year-old biotechnology of yeast. Fermentation begins when the yeast is added to a solution of sugar, water, and milk. Baker's yeast is a unicellular, eukaryotic micro-organism belonging to the fungi and usually the strain of the species Saccharomyces cerevisiae. Two types of baker's yeast are compressed yeast or fresh yeast and dried yeast. Most commercial bakers utilize the traditional compressed yeast, which has high gas production, but is perishable and has a short shelf life. Dried yeast can be found in two forms – active dry yeast (ADY) and

instant dry yeast (IDY). Active dry yeast has irregular particles, which should be re-hydrated with water at 35 – 45° C for optimum gas production.   Instant dry yeast's gas production is comparable to compressed yeast; however, once the IDY package is opened it must be used within a few days. IDY high porosity and rod shape gives easy access of water and oxygen that results in a rather rapid loss of activity on exposure to atmospheric conditions, hence a short "opened" shelf life.

The precise role of yeast in bread making is not fully understood, yet there is now a general agreement that the yeast has a two-fold function, namely leavening of the dough and contributing to the taste and flavor of the bread. Before the mechanical action of kneaders / mixers, yeast functioned in a third role, "maturing or ripening" the dough by utilizing the gas-producing activity to bring about the essential changes in the gluten structure.

The leavening activity or gas production of yeast in dough is the result of the fermentation of sugars. With glucose as the starting material, this process involves a sequence of enzymatic reactions, the sum of which can be represented as follows:

$$C_6H_{12}O_6 \text{ (Glucose)} + 2 \text{ ADP} + 2 \text{ P} \rightarrow$$
$$2 C_2H_5OH \text{ (Ethanol)} + 2 CO_2 + 2 \text{ ATP} + 2 H_2O$$

According to this equation, about 0.29 grams of carbon dioxide or leavening gas, is produced per gram of glucose fermented. At a dough temperature of 30 C and at atmospheric pressure, this would mean 276 ml of CO_2 per gram of glucose fermented. According to a study by H.W. Van Dam, ADY is capable of producing 160 ml of gas per 285 mg of yeast in a time span of 165 minutes in standard dough consisting of flour, water, yeast, sugar, and salt.

The main purpose for the rest or bulk fermentation period is to allow the water to penetrate to the center of the granules and the yeast to re-hydrate. Yeast does not begin to grow until the temperature reaches approximately 30°C. However, if the mixer is not cooled, the mixing action of large mixers can easily raise the temperature to 30°C.

Kneading Process – Incorporation of Air or Gas Phase

The incorporation of air during the mixing is a vital step. These bubbles form the nuclei for gas cells, which later expanded as carbon dioxide from the fermentation process diffused into them. No new cells develop after the mixing/kneading processes, only subdivision of existing cells occurs during punching and molding operations. The grain (gas bubble structure) and volume of the final product are largely determined by the end of the kneading/mixing process. Batch mixers continually draw new, and often large, gas air bubbles during the mixing/kneading process, and the bubbles enfolded near the end of the process will not be completely dispersed. This uneven dispersion creates bread that is courser in grain and the crumb is less uniform. Generally, commercial white breads are manufactured using continuous process mixers to produce fine, uniform grain structure bread with high specific volume.

The ease of beating in air cells depends on the viscosity of the medium, the speed and nature of the mixing, and the concentration and types of surface-active agents present. Stability depends on the initial gas size distribution and on the natural surfactants stabilizing the film. Lipids and proteins are the natural surface-active agents of flour. Lipids are a group of organic compounds, including the fats, oils, waxes, sterols,

and triglycerides, that are insoluble in water but soluble in common organic solvents, are oily to the touch, and together with carbohydrates and proteins constitute the principal structural material of living cells. The lipids form a lamellar liquid crystal line structure, which behave like a plastic fat. This lamellar phase is ideal for stabilization of gas cells and contributes to the gas holding capacity of the dough.

Kneading Process - Dough Development

For highly viscous materials or pseudoplastic materials, which includes dough, laminar flow conditions prevail and the major mechanism of mixing / kneading is shear. Shear performs mixing by drawing out the components into thinner and thinner layers. In practical terms the gluten strands are drawn into a thinner layer by the rotary action of blades, paddles, or helical metal ribbons.

Due to the pseudoplastic nature of bread dough, it is difficult to design an efficient mixer. With bread dough, the viscosity and mixing velocity, two of the most important variables affecting power input, are independent. The apparent viscosity decreases with increasing rate of shear. Therefore, mixer speed and duration is often formulated by trial and error. However, if constant velocity is utilized, the motor torque can be monitored to determine proper dough development.

1st Rise or Intermediate Proofing

Intermediate proofing or the 1st rise period functions as a rest period to allow the gluten fibrils to reorient and a fermentation period to begin the production of carbon dioxide. During proofing, moisture is redistributed throughout the dough piece. Gas production continues, and expands the bubbles that were previously established in the dough. The gluten structure of the dough relaxes, presumably through repositioning of the protein fibers that have been stretched and distorted during the mixing and kneading. Enzymatic reactions continue, forming maltose and dextrose from starches and peptides from proteins. During the intermediate proofing, the dough mixture is raised to a temperature 28°C to 30°C and kept at a relative humidity between 70 and 75 % for approximately 10 minutes. The higher temperature is necessary for the growth of yeast and production of the by-product gases. The humidity affects the elasticity and moisture content of the surface layers of the dough piece. The high humidity is required to prevent drying out or crusting of the surfaces of dough pieces during the time they are in the enclosure. On the other hand, if the humidity is allowed to rise near the dew point, there will exist the danger of the water condensing on the surface of the dough. This will cause spotting on the finished bread surface and a decrease in surface elasticity that will cause splitting of the surface during proofing or baking.

Punch Down or Molding

This process helps to divide the existing bubbles to create a finer and more uniform grain structure. Finer grain structure helps to produces a "white" appearance and high specific volume bread.
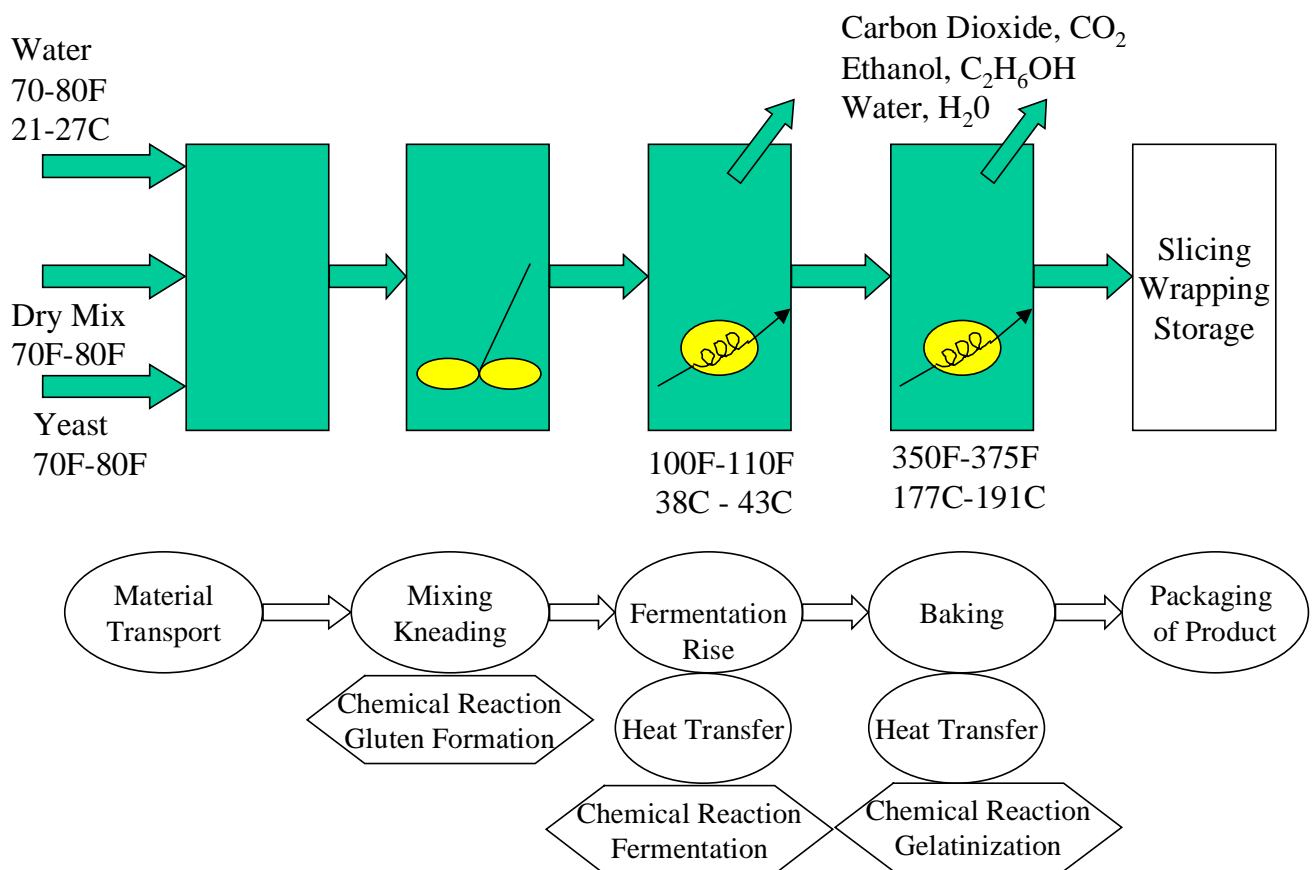
Commercial bakeries utilize dividers, rounders, and molders to produce a "loaf" of bread. During the dividing process much of the gas is pressed out and cutting of gluten strands occurs. The function of rounders is to heal some of this damage. A ball is formed by the rounder which has surface areas of oriented gluten that are partially dried by loss of moisture and addition of dusting flour. This layer acts as a fairly effective barrier to gas diffusion and allows carbon dioxide to accumulate in the interior. Thus the gas vesicles that have collapsed and subdivided during previous processing are once again inflated. A result of dividing, rounding, and molding is that the grain becomes finer and more uniform.

Final Proof, Pan Proof, or Final Rise

Pan proofing or final rise is the stage in which a piece of dough, having previously undergone mechanical manipulation establishes the form of the final product. Once again, expansion and moisture redistribution takes place during pan proofing. The dough begins to fit itself to the pan contours and establish a layer of coalesced vesicles that will be the basis of the crust.

Baking

The baking process serves two functions, to provide oven rise or expansion of dough, and to transform the structure of the dough with separate gas cells, into a solid

Water
70-80F
21-27C

Dry Mix
70F-80F

Yeast
70F-80F

Carbon Dioxide, CO_2
Ethanol, C_2H_6OH
Water, H_2O

100F-110F
38C - 43C

350F-375F
177C-191C

Slicing
Wrapping
Storage

Material Transport → Mixing Kneading → Fermentation Rise → Baking → Packaging of Product

Chemical Reaction Gluten Formation

Heat Transfer

Heat Transfer

Chemical Reaction Fermentation

Chemical Reaction Gelatinization

During the final baking stage, evaporation of carbon dioxide, ethanol, and water occurs. In yeast dough, the liquid dough phase is saturated with carbon dioxide.   The solubility of carbon dioxide in the dough is on the same order of magnitude as the solubility of carbon dioxide in water (0.81×10^{-3} m^3). The solubility of carbon dioxide in water decreases with increasing temperature and most of the dissolved carbon dioxide vaporizes upon baking. In addition, all of the ethanol and a large percentage of the water vaporize during the baking cycle.

Packaging and Storage

The final product is removed from the bread pan, sliced, and packaged for storage and shipment. Cutting and bagging machines are found in large commercial bakeries. The product is then shipped to the stores for retail sale.

Production of Bread
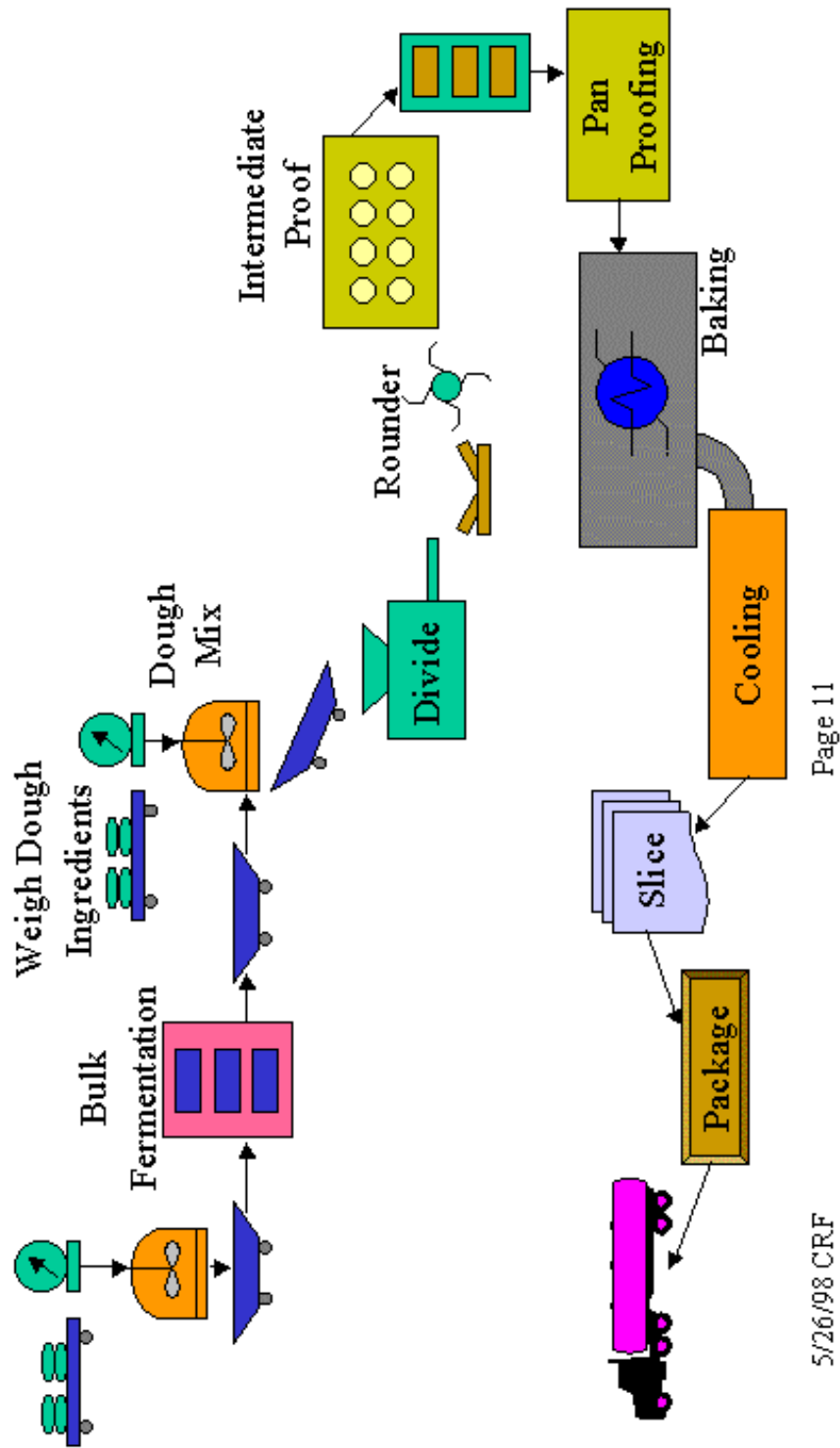
Description of Breadmaker Components

Bread Pan – Aluminum alloy bread pan with nonstick coating. The dimensions of the pan are 5.29" x 5.29" x 5.49" The tapering and rounded corners of the pan produces an approximate volume of 2230 cm3.

Oven Chamber and Heating Element – The dimensions are 7" x 7 ½" x ". A single 430 W heating element with 49.6 KΩ at 25°C encircles the oven chamber. The resistance of the element decreases as it heats up.

Vent and Lid - The unit has a 2 13/16" x 13/16" vent in the lid to exhaust the gas vapors from the heating chamber. The lid is plastic on the outside with an inner metal insert on the interior of the chamber. The lid is equipped with a 1/8" thick, 2 ¾" square sight glass.

Motor and Pulley - ECM Motor CA-161200-T, 01R06, 120 V 60 HZ 30 W.
Motor Shaft
      1755 RPM Full
      1300 RPM Pulse Speed
Pulley Ratio
      130 teeth on kneading blade shaft / 20 teeth on motor shaft
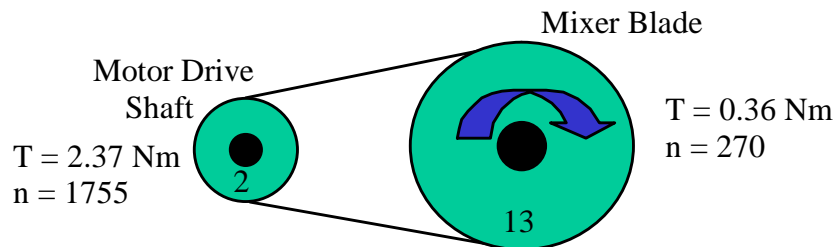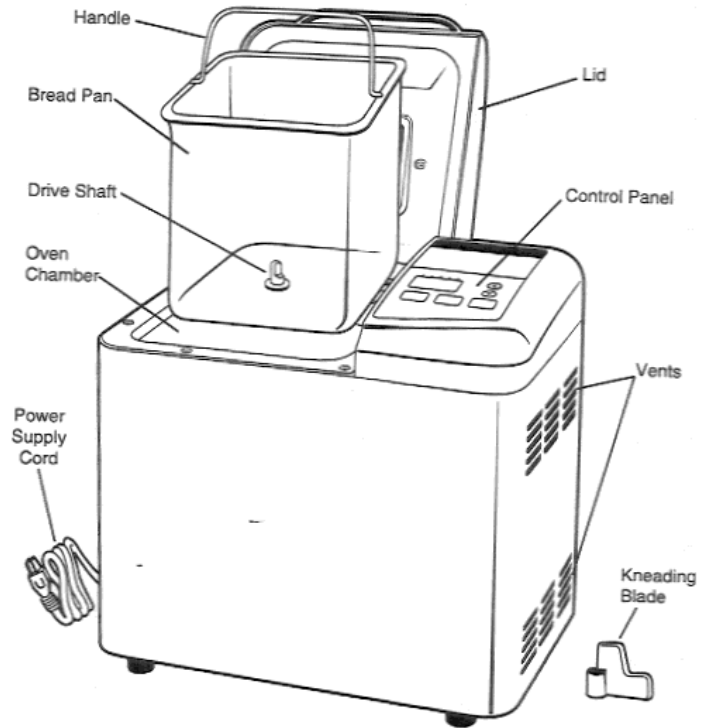   = 6.5 Turn down ratio
Kneading Blade Rotation
      270 RPM Full
      200 RPM Pulse Speed
Motor Load – No load
      0.58 Amps
      67 Watts

Control Board - The breadmaker has two circuit board consists of Liquid Crystal Displays, Push Switches, Resistors, Capacitors, a buzzer, Fuses, Diodes, Quench arcs, a

coil, and a microchip. The unit has temperature feedback, timer capability, and 14 preprogrammed modes.

Framework and Part Construction – The lid and control panel shell of the breadmaker is formed out of a high temperature and impact resistant plastic. The side and bottom of the unit is stamped out of stainless steel. The side panels have been power coated to resist scratching. Rubber pads help to absorb the vibration caused by mixing and kneading.

Experimental Procedure:

This laboratory experiment is divided into several parts. It begins with material appropriate for a freshman level class, followed by sophomore material, then material for a junior level class. The freshman portion involves data acquisition, simple calculations, and taking measurements. The sophomore and junior level portions involve advanced calculations, modeling systems, and mass and energy balances.

Freshman Level Material

1 - Volume of Bread Pan

In order to calculate the final volume of the bread you must know the initial volume of the pan; therefore the first step we take is to measure the volume of the pan. With the kneading blade in the bread pan, fill the bread pan with rice until the rice is level with the top of the bread pan. Use a graduated cylinder to measure the volume of this rice.

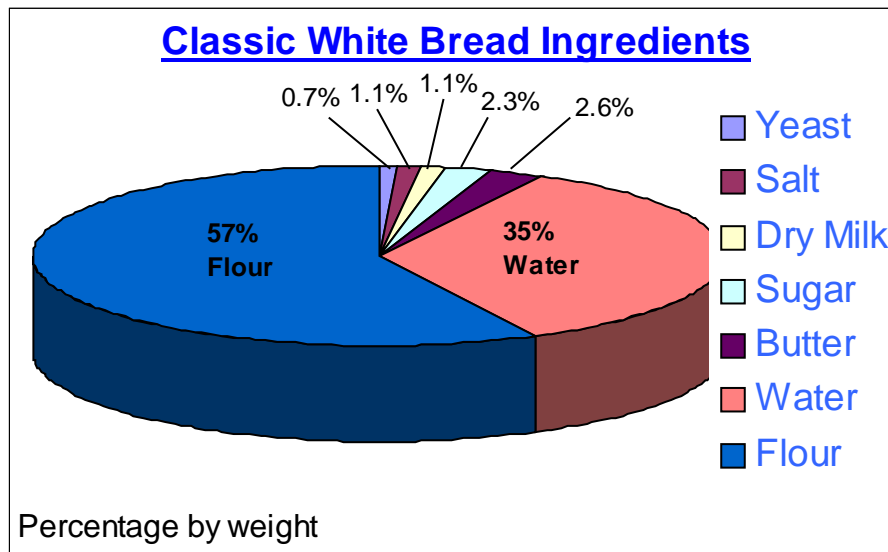2 - Addition of Ingredients and Setting of Breadmaker for a 1 Lb. Loaf

Convert the standard white bread ingredient measurements into standard gram masses, and calculate the standard weight formulation percentage.

					Standard Mass (g)	Percent Mass
Water	235.0	g / cup	6.50	oz	190.9	34.8%
Salt	6.0	g / tsp	1.00	tsp	6.0	1.1%
Butter	225.0	g / cup	1.00	tbsp	14.1	2.6%
Flour	140.0	g / cup	2.25	cup	315.0	57.4%
Dry Milk	100.0	g / cup	1.00	tbsp	6.3	1.1%
Sugar	200.0	g / cup	1.00	tbsp	12.5	2.3%
Yeast	656.0	g / L	1.25	tsp	4.0	0.7%
				Total Mass	548.8	100.0%

8 oz	=	1 cup
48 tsp	=	1 cup
16 tbsp	=	1 cup
1 tsp	=	4.92 mL

Weigh the empty bread pan and kneading blade, then weigh and add the ingredients in the following order:

1. Water – Use 250 ml beaker to measure out approximately 200 ml. Add the standard weight amount – 190.9 grams to the empty bread pan.
2. Salt – Use the small plastic containers to weigh out the standard weight amount – 6 grams.
3. Butter – Use a plastic knife and a small plastic container to weigh out the standard weight amount – 14.1 grams.

4. Flour – Add the flour directly to bread pan. Tare the scale to zero after weighing the bread pan with ingredients 1-3 and add the standard weight amount – 315.0 grams.

5. Sugar - Use the small plastic containers to weigh out the standard weight amount – 12.5 grams.
6. Yeast – Form a small hole in the top of the flour. This will contain the yeast and keep the yeast away from the liquid until the mixing stage begins. Use the small plastic containers to weigh out the standard weight amount – 4 grams.

Classic White Bread Ingredients

0.7% 1.1% 1.1% 2.3% 2.6%

57% Flour

35% Water

- Yeast
- Salt
- Dry Milk
- Sugar
- Butter
- Water
- Flour

Percentage by weight

Once the ingredients have been measured and placed in the pan, weigh the pan with the ingredients in the pan.

Next place the bread pan into the oven chamber with the pan turned a little counterclockwise. To lock the pan in position, turn the pan clockwise (in the direction marked "Lock" on the pan). Make sure the pan has been set securely in the oven chamber to ensure proper mixing and kneading. Close the lid.

Plug the breadmaker into the outlet. The number "0:00" will flash on the display. Choose the proper setting on the breadmaker:

1. Depress the Stop to clear the display.
2. Depress the Select button until the display reads 3. This is the Regular Light Setting on the Regal Breadmaker.

Do not press start at this time.

3 - Data Acquisition Setup:

The breadmaker experiment will use two computers for data acquisition. The first computer will be used to record the temperature of the bread using thermocouples, and the second will be used to record the power usage of the breadmaker during the entire run. Two computers are necessary in this experiment because they record data over different time intervals and use different sampling rates.

On Both Computers:
Once the computer is turned on, open Microsoft Excel. While the program is still loading, you will be asked if you want to open DaqView. Opt "yes". Once the program has completed loading depress the DaqView button in the taskbar to activate the DaqView menu. Press "File", then "Open", and open the file named "settings.daq".

4 – Beginning Data Collection

Once the experiment has been properly set up, begin data collection as follows. Simultaneously depress both the start button on the breadmaker, and the manual trigger on computer #2. Do this by clicking on the green arrow in the top right of the Excel screen, then clicking the button that pops up reading "Manual Trigger". "2:40" will appear on the breadmaker display.
When the timer on the breadmaker reads "2:00", insert the thermocouples into the dough. Then press the manual trigger on the second computer. (At the 1:37 mark, you will need to remove the thermocouples for two minutes while the breadmaker kneads.) Please note that the DaqView program will automatically turn itself off, and write data into Excel.

5- Saving Data and Ending Computer #1 and #2A
Once the data has been collected press the save button. This will save your data in a file called data.xls.

Example Data Acquisition Results
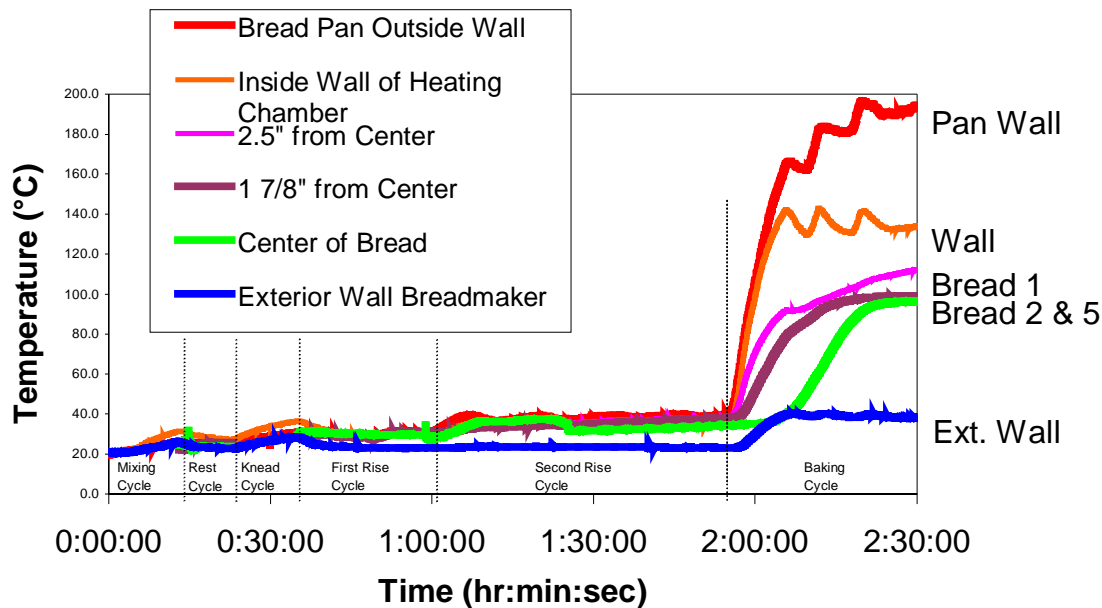
6 - Volume of Bread

Once the bread is finished baking, and has had time to cool, pour rice into the pan until it is level with the top of the pan. Then measure the volume of the rice with a graduated cylinder.

7 – Mass Balance

Weigh the bread, and find the mass of the gases that left the bread by subtracting the mass of the ingredients.

8– Moisture Content

To find the amount of water in the bread, to complete the mass balance, put the baked bread into an oven to completely dry it out. After at least 12 hours in the oven weigh the bread, and subtract this weight from the final weight of the bread to find the amount of water that was in the bread.

9 – Volume of Gas Retained

Given the volume of the dough from prior experiments, subtract the volume of the baked bread to obtain the volume of gas retained. Next calculate the volume of gas that the added amount of yeast can generate. Research states the ADY produces 160ml of gas per 285mg of yeast in approximately 165 minutes. Calculate the loss of gas retention and yeast efficiency due to punching and poor gluten holding capacity. This indicates a minimum amount of CO_2 gas generated by the difference in volume.

10 - Amperage Readings – Analog Conversions

Utilize the wattmeter calibration curve for amperage to correct the analog voltage output. Y =, where x is the analog voltage output and Y is the amperage readings in

amps. Amperage reading indicates the load on the motor. Use the average amperage reading for later calculations. Analyze the amp load during the mixing and kneading cycles. Plot the amp load versus time. As the dough develops, it resists the turning of the mixer blades. This resistance can be related to the amp load on the motor or torque of the motor.

Note: The motor and heating element never run at the same time.

11 - Power Consumption Readings – Analog Conversions and Analysis of Power Consumption Cost

Utilize the wattmeter calibration curve for watts to correct the analog voltage output. Y =, where x is the analog voltage output and Y is the power readings in watts. The power reading indicates the power load at a point in time. Use the average power loads for later calculations. Evaluate the area under the curve to calculate the KWH used to bake the loaf. Calculate the cost using a $0.1215 /KWH. Analyze the pattern of power consumption. Plot power versus time.

Power Consumption of Breadmaker
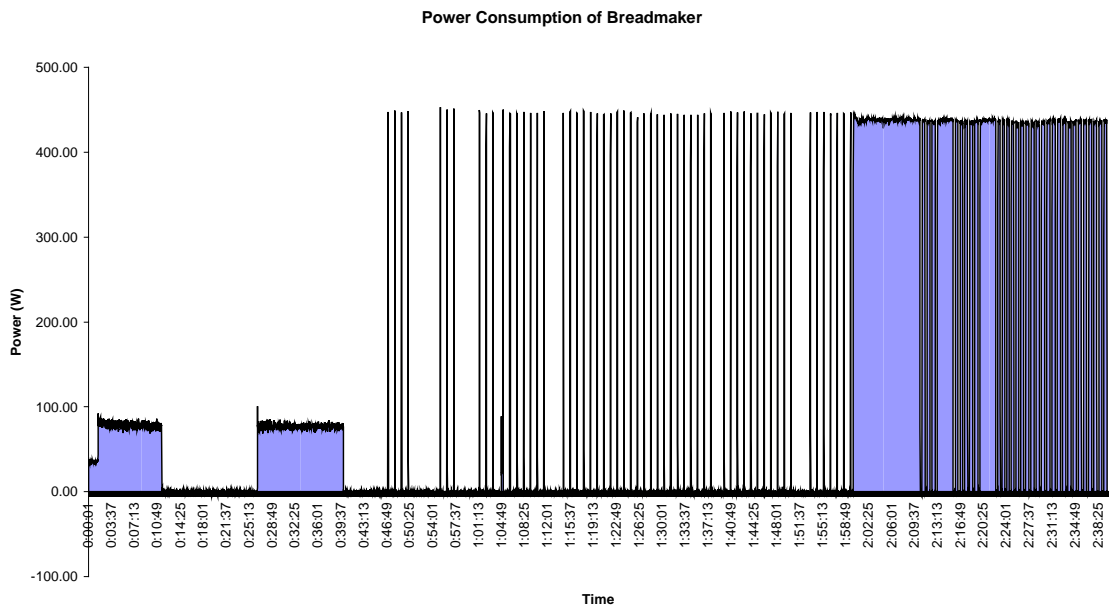
12 – Temperature Analysis

Plot the temperature versus time. Plot temperature versus radial position. Plot temperature versus height.

Sophomore Level

Mass Balance

Like Energy balances, mass balances are very important in chemical engineering. The general form of the mass balance for all of the ingredients is as follows.

$$\Sigma m_{ingedients} = m_{bread} + m_{gasses}$$

Since we know the mass of the ingredients, and the mass of the bread, then we can easily complete this balance, and find the mass of the exit gases. We can also perform a component balance on the water in the bread, which appears as follows.

$$m_{\text{water in flour}} + m_{\text{water}} = m_{\text{water in bread}} + m_{\text{water in gas}}$$

To solve this mass balance we use the literature values for mass of water in flour, the mass of water as an ingredients is known, and we can find the mass of water in the bread by evaporating it out, and taking the initial and final mass. Then we can easily calculate the mass of water that left as a gas.

Junior Level

Energy Balance

There are several energy balances that a junior level student can perform, such as a balance over the bread, and over the machine. The balance over the bread is as follows.

$$\frac{dE}{dt} = E_{in} - E_{out}$$

Where the only energy in is through the wattmeter, and the energy out can be called 'Losses'. Since we know that not all of the energy from the heater reaches the loaf of bread we can put a constant in front of the energy in term. This means that our equation appears as follows.

$$\frac{dE}{dt} = \zeta * Watts - Losses$$

Since we know that the air surrounding the bread dough is hotter than the dough itself, it follows that the only losses are those from the gasses leaving the dough as it cooks. Since H_2O is the only significant gas that leaves the bread, the Losses term changes as follows.

$$Losses \approx -H_{H_2O} * m_{H_2O}$$

If $m*Cp*T$ is substituted for E then the energy balance can be solved, if C_p, mass flow-rate of the gas, enthalpy of the gas, initial and final temperature, and initial and final time are known.

The other type of energy balance is a balance over the breadmaker instead of over the bread. The balance over the bread maker has the same general form, but instead evolves as follows.

$$\frac{dE}{dt} = Wattmeter - Losses$$

In this case we know that all of the watts are going into the breadmaker, and that the losses term encompasses gasses, and convective losses due to heat transfer. To find the heat transfer coefficient we approximate the surfaces of the breadmaker as smooth horizontal and vertical plates. We can further simplify the calculations by using approximate equations. As such the calculations are as follows.

Horizontal Surface: $h = 1.32(\frac{\Delta T}{L})^{1/4}$

Vertical Surface: $h = 1.42(\frac{\Delta T}{L})^{1/4}$ (From p 358 of Heat Transfer by J.P. Holman)

Where ΔT is the difference between air temperature and wall temperature (if the temperature at the center of the wall is used calculations are still accurate), and L is the length of one side of the square surface. Although these numbers are approximations, the approximation is very good. Once all of the convective heat loss coefficients have been found, you can find the heat loss through each of the surfaces, sum them, and also add the heat loss for the gasses leaving. Once this is done, you will have completed the energy balance.

Alternative Studies:

Viscosity of Dough During Mixing, Kneading, and Dough Development

As the dough develops, it resists the turning of the mixer blades. This resistance can be related to the amp load on the motor or torque of the motor. The resistance can also be measured by a Cup-Type Viscometer; measure the viscosity at different stages of mixing.

Environment - Water

Water is a major ingredient of bread and the quality of the water affects the quality of the bread. Measure the pH and conductivity of the water. Measure the hardness. Use distilled or RO water to make the bread. Compare the quality of the bread.

Environment – Gas Evolution

Measure the CO_2 and Ethanol Emissions. The gauge-type instrument reads the pressure developed in a sealed bomb after a given time, while the manometric apparatus allows the lab to follow the evolution of gas as a function of time. The manometric equipment is less expensive. Research bakery emission regulations.

Particle and Bubble Size Distribution

Analyze the particle size distribution of the bread. Vary mixing time to establish effect on grain size.

Materials of Construction

Investigate materials of construction such as, nonstick coating, ceramic fiber seal, aluminum alloy bread pan, plastic parts, rubber feet, etc. Investigate improving the quality of product and / or cost by material substitution and upgrade.

Design Improvements

Test different possible design improvements to optimize the bread making process. These improvements could include finding the optimal temperature for yeast activity, reducing oven temperature, controlling the humidity of the dough as it cooks, and many other things.

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Biographical Information

C. Stewart Slater is Professor and Chair of Chemical Engineering at Rowan University. He received his B.S., M.S. and Ph.D. from Rutgers University. Prior to joining Rowan he was Professor of Chemical Engineering at Manhattan College where he was active in chemical engineering curriculum development and established a laboratory for advanced separation processes with the support of the National Science Foundation and industry. Dr. Slater's research and teaching interests are in separation and purification technology, laboratory development, and investigating novel processes for interdisciplinary fields such as biotechnology and environmental engineering. He has authored over 70 papers and several book chapters. Dr. Slater has been active in ASEE, having served as Program Chair and Director of the Chemical Engineering Division and has held every office in the DELOS Division. Dr. Slater has received numerous national awards including the 1999 and 1998 Joseph J. Martin Award, 1999 Chester Carslon Award, 1996 George Westinghouse Award, 1992 John Fluke Award, 1992 DELOS Best Paper Award and 1989 Dow Outstanding Young Faculty Award.

Robert Hesketh is Associate Professor of Chemical Engineering at Rowan University. He received his B.S. in 1982 from the University of Illinois and his Ph.D. from the University of Delaware in 1987. After his Ph.D. he conducted research at the University of Cambridge, England. Prior to joining the faculty at Rowan in 1996 he was a faculty member of the University of Tulsa. Robert's research is in reaction engineering, novel separations including supercritical fluids and ultrafiltration, green engineering, an the

chemistry of gaseous pollutant formation and destruction related to combustion processes. Robert employs cooperative learning techniques in his classes. His teaching experience ranges from graduate level courses to 9th grade students in an Engineering Summer Camp funded by the NSF. Robert's dedication to teaching has been rewarded by receiving several educational awards including the 1999 Ray W. Fahien Award, 1998 Dow Outstanding New Faculty Award, the 1999 and 1998 Joseph J. Martin Award, and four teaching awards.

Carol Rea Flynn was a graduate student at Rowan University and now works for Wheaton.